FINAL REPORT
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CARBON DIOXIDE ENHANCED PRESSING OF FAT FROM RENDERED MATERIALS

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Lay Summary: The goal of this work is to investigate the use of carbon dioxide (CO_2) as a green solvent for applications in the rendering industry. This includes value-added co-products for energy, consumer products, and commodity chemicals/materials. Certain opportunities exist within the rendering industry for enhanced separations that will preserve value added content within the rendered material. This research has focused on the use of supercritical and liquid CO_2 to enhance the fat separation during the mechanical pressing of rendered materials at industrial relevant scales. Our prior work demonstrated the ability to enhance the mechanical expression of fat from a ground poultry meal where up to 81% of the residual fat in the poultry meal was recovered by mechanically pressing the poultry meal in the presence of supercritical CO_2.[1-2] In other words, the fat content of the ground poultry meal was reduced from the initial 12.1% to a final 2.3% after pressing in a lab-scale batch press operating at 40°C, 3000 psi of CO_2, and 8700 psi mechanical pressure. Based on these results, we have conducted pilot scale studies at the Crown Iron Works R&D Test facility in Roseville, MN.[3]

Objective (s): The focus of this proposal is to continue and extend our recent work to the pilot plant testing. Our prior work has demonstrated the potential enhancements that CO_2 assisted pressing can achieve. The next step is to test the process on the pilot scale where CO_2 enhanced pressing will be performed in a continuous press at a rate up to 1 ton per hour. These pilot scale experiments will be performed at the Crown Iron Works pilot plant facility in Roseville MN. The local contacts at Crown are Bruce MacKinnon and Chas Teeter. At the pilot plant, Crown has a demonstration unit referred to as High Pressure Liquid Extraction (HIPLEX). HIPLEX is a mechanical screw press designed to inject liquid CO_2 into the press to enhance the oil recovery from seeds. Crown developed this technology with Harburg-Freudenberger (HF) and currently it is proprietary to HF presses, however it could be theoretically applied to other press manufacturers. To date, this technology has been geared to soybean and seed oil recovery but there is potential for application to rendered materials. The goal of this work is to explore the extent to which the HIPLEX system can be used to enhance the fat recovery from meat and bone meal (MBM). Specific objectives of this work will include:

1. Determining the optimal operating parameters for HIPLEX with green (high fat content) and pressed (low fat content) ruminant meat and bone crax.
2. Correlate the operating parameters for HIPLEX with fat expression yield.
3. Explore alternative methods of recovering fat from DAF sludge and recycle flocculants.
4. Explore the potential for CO_2 pretreatment of the meat and bone crax before pressing

Project Overview:

Work on this project began in April 2014 with the planning of our pilot-scale trials to test the CO_2 enhanced pressing of rendered materials at the Crown Iron Works pilot scale test facility in Roseville MN using their HIPLEX system. HIPLEX is a mechanical screw press designed to inject liquid or supercritical CO_2 into the press to enhance the oil recovery from seeds. Crown developed this technology with Harburg-Freudenberger (HF) and is proprietary to HF presses. The HF PIPLEX press is shown in the picture below. The rendered material is fed by a variable speed screw feeder onto a series of conveyors to continuous cooker was used to bring the temperature up to 260 °F before it is fed into the press with a screw feeder. The material is then pressed, exiting on the right side and conveyed to collection totes. The novelty of this press system that sets it apart from anything else in the industry is the ability to expose the cake to 3900 psi of CO_2 during the press. This is achieved through the design of the press cage with specific lining bars, high pressure injectors and a press shaft configuration that allows for the formation of a plug seal with the cake at the front and end of the press cage. This results in a 12-16 inch long section where the cage expands in volume allowing for the cake to be exposed to high pressure CO_2 in the absence of mechanical pressure. This is vital to enable the CO_2 to penetrate into the matrix. A schematic of the press cage configuration is shown in Figure 2.

Figure 1. Picture of the HIPLEX System at Crown Iron Works Pilot Testing Lab, Roseville, MN

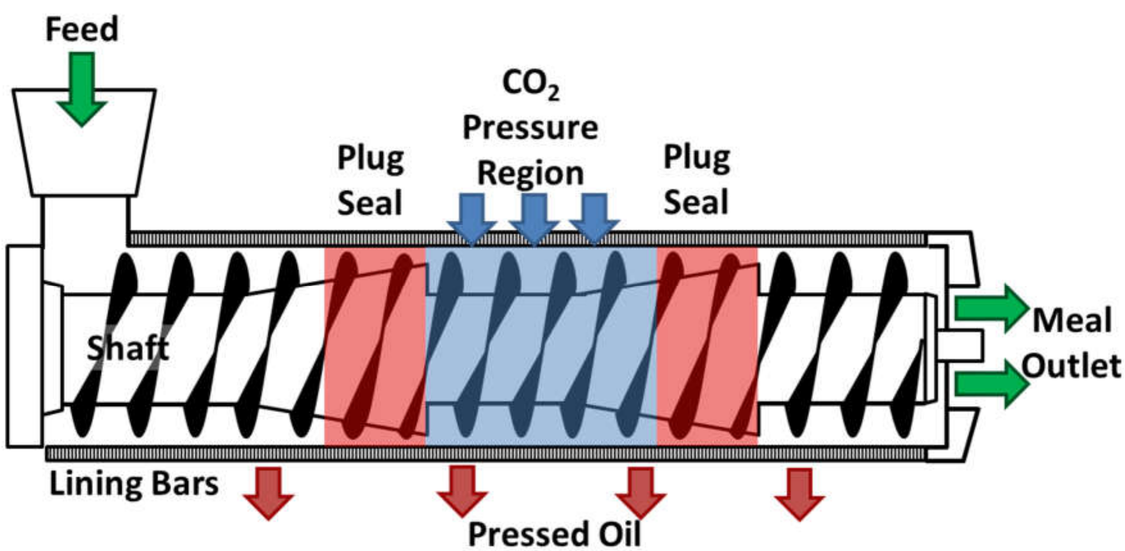

Figure 2. Schematic of the HIPLEX Press cage configuration.

Along with the added capabilities of the HIPLEX system over conventional presses, comes additional parameters that influence the resulting pressing efficiency and residual fat content in the rendered materials. Specifically, the addition of high pressure CO_2 to the cage results in a rapid expansion of the CO_2 and thus substantial cooling of cake within the press due to the Joule-Thompson expansion. Decreased cake temperature can significantly decrease the viscosity of the fat component and thus reduce the ability to press the fat from the cake. To counteract this effect, the CO_2 can be heated to 190^{o}F before injection. Conventional press parameters include the material feed rate (lb/min), press load (Amps), press speed (RPM/Hz), and temperature. For HIPLEX, the added parameters include CO_2 feed rate (lb/min), CO_2 pressure (psi), and CO_2 temperature (^{o}F); each of which will affect the cake temperature. Furthermore, it should be noted that in order for the HIPLEX system to maintain CO_2 pressure within the cage, the two plug seals depicted in Figure 2 must be maintained, which results in significant limitations in the press operating parameters (material feed rate, press load, and press speed) which are largely dictated by the material feed composition, temperature, etc. and is highly variable. Thus, day to day and feed to feed variability can influence the range of operating parameters that can be tested. This results in difficulty for conducting a systematic parametric study of each independent variable. In order to overcome these difficulties, we must compile our results over multiple independent trials we have conducted over the past two funded projects.

RESULTS AND DISCUSSION:

Prior research was focused on configuring and designing the HIPLEX system to accommodate rendered materials – see prior progress reports. Recent research progress has entailed, improving our sampling techniques and analyzing processing parameters to draw conclusions from the recent pilot plant trials. The pilot plant runs conducted will be discussed in terms of two different trials. The first trial consisted of three days of testing from June 17th to 19th 2015. This trial included testing Green Poultry Crax (left) and Green MBM Crax (right), shown in Figure 3 and the results are listed in Table 1. A second trial was conducted March 30th – April 1st 2016. This trial was focused on a broader parametric study with Green Poultry Crax alone and the results are detailed in Table 2.

Figure 3. Images of green poultry crax and green MBM crax.

Table 1. Results from pilot trials at Crown Iron Works on June 18-19, 2015.

Crax	CO2 Press. (psi)	CO2 Temp. (°F)	Amp Load	Cake Temp. (°F)	Fat (%)
Poultry	0	-	75	250	13.8
Poultry	3900	30	75	250	13.1
Poultry	3900	190	75	250	11.1
Poultry	0	-	95	210	8.1
Poultry	3900	30	85	175	12.5
Poultry	3900	185	65	200	7.4
MBM	0	-	125	225	10
MBM	3900	30	150	200	17.4
MBM	3900	185	110	212	15.1

Within trial 1, two set of results were obtained for the green poultry crax that show the effects of CO_2 pressure, temperature and amp load on the resulting fat content. The most significant result is that the fat content was 2.7% lower (13.8% to 11.1%) with the use of heated CO_2 at similar operating parameters, a 20% fat reduction. This 20% reduction in fat content was achieved with a load of 75 amps on the press and a constant Cake temperature of 250 °F. The heated CO_2 consistently performs better than the CO_2 that is not heated. When the high pressure CO_2 undergoes rapid expansion in the press, the Joule-Thompson effect results in significant cooling. To counteract this, the CO_2 is heated to a supercritical state at 185°F prior to injection. Use of liquid CO_2 at 30°F can on instance result in lower CO_2 pressing efficiency (a 5% reduction from 13.8% to 13.1%) due to the lower temperature effect.

Analysis of the green poultry crax results also indicate that the addition of CO_2 can also decrease the amperage load on the press, which translates to less energy consumption by the press and less heat generation due to the friction between the rendered material and the press shaft. The lower cake temperature is important because local hot spots at the shaft interface can lead to charring of the rendered material, which degreases the nutritional content. The second set of poultry crax numbers show that with the use of heated CO_2, an 8.6% lower fat content (7.4% vs 8.1%) can be achieved with significantly lower force applied (65 amps vs. 95 amps). The ability to press the fat from the crax is a balancing act in terms of the operating parameters. Increased amperage can result in lower fat content but requires more energy and can result in cake charring. Temperature effects are also significant where higher temperature can result in lower fat content but again, cake charring can be an issue. Our results demonstrate that the use of heated CO_2 mitigates the cooling effects and enables increased pressing efficiency at decreased loads.

The results from the MBM pilot trials were not favorable and showed higher fat content with the use of CO_2. This can be attributed to several factors. First, the press configuration is set up for poultry and not MBM. Similar results were also obtained with our first poultry crax trials but following the press reconfiguration, favorable results were obtained. Second, the material feed system was not set up to accommodate the large pieces of bone in the MBM which led to inconsistencies. We believe that similar favorable results can be achieved with MBM crax by designing a press configuration and material conveying system that is appropriate for the MBM. It is known in the industry that there are specific differences in the press configuration and shaft design that are more favorable for pressing MBM versus poultry crax. Based on these factors, we are not placing a large amount of confidence in these results for MBM.

Results from the poultry green crax parametric study beginning on 3/30/16 are listed in Table 2. In this trial, the press load and speed were kept constant once the poultry green cracks were feeding through the press and holding CO_2 pressure. Comparison of runs 1 and 8, both without CO_2, demonstrates the effect of cake temperature and material feed rate on the remaining fat content. Lower temperature and higher feed rate for a given shaft speed will both decrease the amount of fat pressed from the matrix. Comparison of runs 1, 2, and 3 demonstrate that an increased crax feed rate with a low CO_2 feed rate results in a decreased cake temperature and marginal yet significant decrease in the amount of fat pressed from the cake. For run 4, the addition of heated CO_2 at a higher flow rate of 3.3 lb/min demonstrates that the same fat content can be achieved at a significantly lower cake temperature (187°F vs 225°F). The green crax contains a fat content of 46%, thus a crax to CO_2 feed ratio of 7.0:3.3 results in a roughly 1:1 CO_2 to Fat mass ratio. Run 5 demonstrates that a higher crax feed rate with the same CO_2 flow rate results in decreased fat expression. This can be explained by decreased resonance time in the press and decreased time of exposure to CO_2 in the pressurized zone of the press. Runs 6 and 7 confirm our prior observations that cold CO_2 can significantly lower the cake temperature and greatly reduce the fat expression.

Table 2. Run parameters and results from Trial 2 with Poultry Green Crax.

Run	Crax Feed Rate	CO2 Feed Rate	CO2 Cond.	CO2 Temp	CO2 Press.	Press Load	Press Speed	Cake Temp	**Fat**	Std. Dev.
	lb/min	lb/min		°F	PSI	Amp	RPM/hrtz	°F	**%**	
1	6.4	0.0	NA	NA	NA	56	(45 / 60)	225	**13.5**	0.3
2	8.6	0.5	Hot	0	3900	56	(45 / 60)	185	**14.3**	0.3
3	8.1	0.2	Hot	171	3900	56	(45 / 60)	185	**14.7**	0.1
4	7.0	3.3	Hot	193	3900	57	(45 / 60)	187	**13.6**	0.2
5	9.0	3.3	Hot	198	3900	57	(45 / 60)	190	**17.3**	0.2
6	5.6	1.8	Cold	55	3900	56	(45 / 60)	150	**21.1**	0.1
7	6.4	1.5	Cold	28	3900	56	(45 / 60)	150	**21.6**	0.2
8	8.6	0.0	NA	NA	NA	56	(45 / 60)	165	**22.4**	0.2

ECONOMICS

If considering a 25 ton/day operation with the HIPLEX system the economics would include $1.2 MM in equipment with an additional $1 MM to $500k for site location. Utilities would require 0.05 kWhr/ton and 4.5 lb steam/ton with a 1:3 CO_2:product ratio at $30/ton CO_2. Timeline would involve 6 months for press configuration, install, and parameter optimization. If the HIPLEX can provide an additional 2% fat, this will give additional $300/day at $0.30/lb fat but will require $250/day for CO_2. Thus, additional value must come from somewhere else. This may include a higher value fat or meal product, specifically a premium on a low fat content meal with high nutritional content. Regardless, or economic consideration, an excess of 4% decrease in residual fat must be achieved.

CONCLUSIONS: Our results demonstrate that the use of heated CO_2 can enhance the recovery of fat from rendered materials. Heated CO_2 is required to mitigate the cooling effects and enables increased pressing efficiency at decreased loads (Objectives 1 and 2). The ability to increase fat yields by 20% with the use of CO_2 in a continuous, industrial scale process is significant, however this level of enhancement in not likely to be economically viable. Albeit, for in-plant operation, further improvement of the press configuration and optimization of the operating parameters will enable further improvement in the extraction efficiency, but it is unclear how much. The ability to obtain a low-fat meal without the use of solvent extraction is significant, particularly if a fat content of 6% is achievable without degrading the nutritional content. This is not easily achieved in conventional presses without thermally degrading the meal.

A majority of our work was conducted on poultry green crax, which demonstrated the greatest success as the matrix consistency was best matched to the shaft and press configuration. Finished or ground poultry meal was not effective due to significant foots and the cage configuration. We attempted to apply the HIPLEX system to a DAF sludge material but it did not press well either, likely due to the lack of hard solids for pressing (Objective 3).

The limitations of the HPLEX system lies in the mass transfer limitations for the CO_2 to penetrate the cake matrix in the pressurized zone of the press. This region is on the order of 12 to 16 inches in length, which results in a CO_2 exposure time of less than 60 seconds. The result is inadequate CO_2 solubilization within fat component, which is required to reduce the viscosity by an order of magnitude as predicted from equilibrium data and thus significantly enhance expression efficiency. If progress is to be made with CO_2 enhancement of fat expression, then the mass transfer limitations must be overcome. This would require greater resonance time in the CO_2 pressurization zone or a CO_2 preconditioning step prior to entering the press. We have explored these options but were unable to find a method for CO_2 preconditioning on a continuous or industrial scale (objective 4).

SIGNIFICANCE TO THE RENDERING INDUSTRY: The potential to enhance fat isolation in the industry seems extremely promising with the CO_2 assisted mechanical pressing. Since the last progress report, the German counterparts with HF have become more interested in this work and were very helpful in the press shaft reconfiguration.

Publications: We have two prior publications regarding this work in the Journal of Supercritical Fluids. We are in the process of writing the manuscript for the results presented here.

Outside funding: We have a recently funded project from the USDA project (4 year, $500k) to investigate the use of MBM as an organic fertilizer amendment. Dr. Kitchens is collaborating with Dr. Nishanth Tharayil (Plant Sciences) and Dr. Chris Ray (Experiment Station) to use extracted MBM as a N and P nutrient source for delayed release fertilizers. The focus of this study is to understand how to control the metabolic release of nutrients with various additives to complement chemical fertilizers. This will be done on the lab scale and extend to field trials.

Another side project we are exploring is the use of rendered fats as an asphalt or cement release agent for truck beds. We were approached by a small company in SC to develop a new release agent and hope to provide a new customer for rendered fats.

Future Work: At this point, there is limited future work pertaining to CO_2 enhanced pressing. Our research is transitioning to alternative solvent extractions as a method to upgrade and recycle DAF sludge.

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